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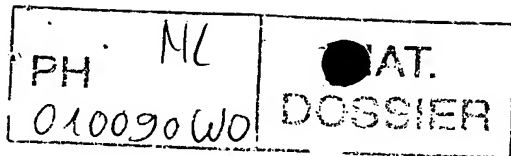
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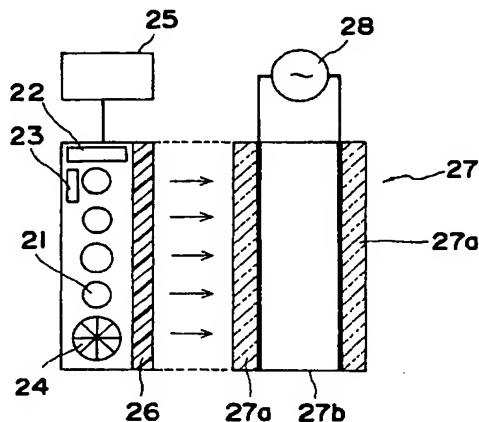
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(54) **Active matrix liquid crystal display.**

(57) An active-matrix liquid crystal display including a liquid crystal panel (27) in which temperature, tilt angle, driving voltage or storage capacity gradually change from an upper portion of the liquid crystal panel (27) towards a lower portion of the liquid crystal panel (27), in order to improve the uniformity of contrast and brightness.

*Fig. 3*



BACKGROUND OF THE INVENTION

## 1. Field of the Invention

5 The present invention generally relates to a liquid crystal display element and more particularly, to an active-matrix liquid crystal display in which display material such as liquid crystal is driven by AC by using a switching element such as a thin film transistor (TFT) so as to display images.

## 2. Description of the Prior Art

10 Image quality of known active-matrix liquid crystal displays has been greatly improved recently. However, it is still impossible to say regarding flicker, changes of brightness in a vertical direction of a display screen, i.e., brightness inclination, image sticking phenomenon in which immediately after display of a fixed image, the fixed image remains as in a printed state, display performance of gradations, dependence on viewing angle, etc., the known active-matrix liquid crystal displays are not inferior to  
 15 cathode-ray tubes (CRTs). Especially, improvement of dependence on viewing angle is one of vital problems to be solved in the known liquid crystal displays showing trends towards larger screens.

Generally, image quality of the liquid crystal displays largely depends on viewing angle. That is, image quality changes greatly according to angle for viewing a display screen. Thus, in a liquid crystal display  
 20 having a large screen, such a phenomenon takes place in which when the display screen is viewed from a viewing point, a displayed image is not uniform at upper and lower portions of the display screen so as to have brightness inclination in a vertical direction of the screen.

Usually, display mode of known active-matrix liquid crystal display elements is twisted nematic (TN) mode in which liquid crystal molecules are aligned so as to be twisted at an angle of 90° between two  
 25 substrates. At this time, liquid crystal molecules in the vicinity of boundaries of the substrates are aligned at right angles to each other so as to be twisted clockwise or counterclockwise from one substrate to the other substrate.

Such alignment of liquid crystal molecules is obtained by rubbing an alignment layer. A direction of viewing angle, in which maximum contrast can be obtained, (referred to as a "principal viewing angle direction", hereinbelow) is determined by a direction of rubbing. In the known liquid crystal displays, optical  
 30 design is usually made such that the principal viewing angle direction is oriented towards an upper portion or a lower portion of a liquid crystal panel. Therefore, viewing angle property of the known liquid crystal displays usually exhibits symmetric optical characteristics in a lateral direction of the liquid crystal panel but unsymmetrical optical characteristics in a vertical direction of the liquid crystal panel. Especially, in a  
 35 normally white mode for performing white display at the time of no application of voltage, nonsymmetry of optical characteristics in the vertical direction of the liquid crystal panel is conspicuous.

In order to correct brightness inclination in the vertical direction of the liquid crystal panel, a method in which amplitude of image signal is changed at upper and lower portions of the display screen is known from, for example, Japanese Patent Laid-Open Publication Nos. 61-261794 (1986), 61-278892 (1986), 62-  
 40 43624(1987), 62-178929 (1987), 1-191196 (1989), 3-294822 (1991) and 4-258921 (1992). However, in this known method, processing of the image signal becomes extremely complicated and load on a driver IC for driving liquid crystal is also large.

On the other hand, an attempt is also made in which dependence on viewing angle in the vertical direction of the liquid crystal panel is lessened by structure of the liquid crystal panel. In Japanese Patent  
 45 Laid-Open Publication No. 3-65926 (1991), Mr. Shunji Suzuki teaches that by changing thickness of a liquid crystal layer at respective display pixels from an upper portion of the liquid crystal panel to a lower portion of the liquid crystal panel, input signal voltage-light transmission characteristics (referred to as "VT characteristics", hereinbelow) at the pixels, namely, dependence of VT characteristics on viewing angle is changed so as to make VT characteristics at the respective pixels approximately equal to each other when  
 50 viewed from a specific viewing point such that dependence on viewing angle is improved. However, this method lays a heavy burden on a production process of the liquid crystal panel and thus, is not suitable for practical use.

SUMMARY OF THE INVENTION

55 In response to progress of technology of liquid crystal display, a liquid crystal panel becomes larger in size. In a liquid crystal panel of a size corresponding to a work station, angle for viewing the liquid crystal panel changes greatly at upper and lower portions of the liquid crystal panel. Thus, such a problem arises

that even if an identical image is displayed, contrast and brightness level change markedly at the upper and lower portions of the liquid crystal panel.

The present invention has for its object to improve dependence on viewing angle inherent in conventional active-matrix liquid crystal displays. The present invention is designed to lessen brightness inclination in a vertical direction of a liquid crystal panel due to dependence on viewing angle of a display by a simple method requiring no complicated image signal processing. Meanwhile, the present invention is designed to improve dependence on viewing angle without utilizing a complicated production process.

Concrete arrangements of the present invention are as follows.

The present invention has at least one of the following features (a) to (d).

(a) Temperature of the liquid crystal panel changes gradually from an upper portion of the liquid crystal panel towards a lower portion of the liquid crystal panel.

(b) Tilt angle of liquid crystal molecules changes gradually from the upper portion of the liquid crystal panel towards the lower portion of the liquid crystal panel.

(c) Magnitude of amplitude of driving voltage applied to a liquid crystal layer by a specific driving scheme changes gradually from the upper portion of the liquid crystal panel towards the lower portion of the liquid crystal panel.

(d) Magnitude of storage capacity changes gradually from the upper portion of the liquid crystal panel towards the lower portion of the liquid crystal panel.

In the specific driving scheme, an active-matrix liquid crystal display comprises: a plurality of first lines; a plurality of pixel electrodes which are disposed in a pattern of a matrix and are connected to the first lines through capacitors; an image signal line; a scanning signal line; a switching element which is electrically connected to the image signal line and the scanning signal line and is connected to each of the pixel electrodes; a counter electrode; and liquid crystal which is held between each of the pixel electrodes and the counter electrode and is subjected to AC drive; wherein when during an ON period of the switching element, an image signal voltage obtained by inverting polarity of a signal voltage is supplied to the pixel electrodes per field of a display screen and during an OFF period of the switching element, a first modulation signal having a polarity opposite to that of the image signal voltage is supplied to the first lines per field of the display screen, potential of the pixel electrodes is changed such that a voltage obtained by adding or eliminating a change of the potential of the pixel electrodes and the image signal voltage to each other is applied to the liquid crystal; wherein the first modulation signals supplied to the first lines, respectively are different from one another.

Preferably the specific driving scheme is applied to an active-matrix liquid crystal display in which during the ON period of the switching element (3), the image signal voltage is supplied to the pixel electrodes, wherein the first modulation signal  $V_e(+)$  of the positive polarity is supplied to the scanning signal line during the OFF period of the switching element in an odd field and the first modulation signal  $V_e(-)$  of the negative polarity is supplied to the scanning signal line during the OFF period of the switching element in an even field so as to change the potential of the pixel electrodes, wherein supposing that a modulation signal amplitude  $V_{pp}$  is defined as  $V_{pp} = |V_e(+)-V_e(-)|$ , a modulation signal amplitude  $V_{pp}(n)$  for an n-th scanning signal line and a modulation signal amplitude  $V_{pp}(n+1)$  for an (n+1)-th scanning signal line have the following relation:  $V_{pp}(n) \leq V_{pp}(n+1)$  or  $V_{pp}(n) \geq V_{pp}(n+1)$  where character n denotes an arbitrary natural number.

Hereinbelow, a basic principle of improvement of dependence on viewing angle in the present invention is described. Such a phenomenon that contrast or brightness level at the upper portion of the liquid crystal panel is quite different from that at the lower portion of the liquid crystal panel even if an identical image is displayed takes place because angle for viewing the liquid crystal panel at the upper portion of the liquid crystal panel is different from that at the lower portion of the liquid crystal panel. Fig. 1 shows a liquid crystal panel P having an upper portion P1 and a lower portion P2. The liquid crystal panel P has a width of 250 mm from the upper portion P1 to the lower portion P2. A normal N relative to a display screen of the liquid crystal panel P is passes through a center C of the liquid crystal panel P. In a liquid crystal display in which liquid crystal molecules are aligned such that principal viewing angle direction is oriented towards the upper portion P1 of the liquid crystal panel P, when the display screen is viewed on the normal N at a distance of 300 mm from the display screen, the upper portion P1 of the liquid crystal panel P is viewed at angles  $\theta$  of  $22.6^\circ$  and  $\phi$  of  $0^\circ$ , while the lower portion P2 of the liquid crystal panel P is viewed at angles  $\theta$  of  $-22.6^\circ$  and  $\phi$  of  $180^\circ$ . In Fig. 1, viewing angles ( $\theta$ ,  $\phi$ ) are defined as shown. Namely, the display screen is viewed along a line E forming an angle  $\theta$  with the normal N. The line E is projected onto the display screen as a line E'. When X-Y coordinates are established on the display screen as shown in Fig. 1, the line E' forms an angle  $\phi$  with the X-axis. When the display screen is viewed from the lower portion P2 of the liquid crystal panel P as shown in Fig. 1, the angle  $\theta$  is set positively. On the contrary, when the display

screen is viewed from the upper portion P1 of the liquid crystal panel P, the angle  $\theta$  is set negatively.

More specifically, the phenomenon that contrast or brightness level at the upper portion of the liquid crystal panel is different from that at the lower portion of the liquid crystal panel is caused by the fact that dependence of VT characteristics on viewing angle at the upper portion of the liquid crystal panel is different from that at the lower portion of the liquid crystal panel. Figs. 2a and 2b illustrate typical dependence of VT characteristics on viewing angle in a liquid crystal display element in which liquid crystal molecules are aligned such that principal viewing angle direction is oriented towards the upper portion of the liquid crystal panel. When the liquid crystal panel is viewed on the normal at a distance of 300 mm from the liquid crystal panel, the upper portion of the liquid crystal panel has VT characteristics shown in Fig. 2a, while the lower portion of the liquid crystal panel has VT characteristics shown in Fig. 2b.

VT characteristics in an identical liquid crystal material depend on temperature of the liquid crystal panel, gap of the liquid crystal panel, tilt angle of liquid crystal molecules at a boundary surface of an alignment layer, twisting angle of the liquid crystal molecules, sticking angle of a polarizer and magnitude of storage capacity. Therefore, if a liquid crystal panel can be produced in which these conditions change from an upper portion of the liquid crystal panel towards a lower portion of the liquid crystal panel, dependence of optical characteristics on viewing angle can be improved. However, among the above conditions, it is difficult from a standpoint of processing and therefore, impractical to continuously change gap of the liquid crystal panel, twisting angle of the liquid crystal molecules and sticking angle of the polarizer.

On the other hand, in a sense that profile of VT characteristics is changed, driving scheme may also be employed to the end in the same manner as the above mentioned material design and optical design. Namely, also when VT characteristics are shifted to a high-voltage side or a low-voltage side, similar satisfactory effects can be gained.

In case the switching element is a TFT, potential change  $C_{gd} \cdot V_g / \Sigma C$  ( $\Sigma C$  = overall electrostatic capacity per pixel) relative to the image signal is induced in a negative direction through a capacity  $C_{gd}$  between a gate and a drain by potential change  $V_g$  of a scanning signal. Thus, when the unsymmetrical positive and negative first modulation signals  $V_e(+)$  and  $V_e(-)$  in which polarity is inverted per field are applied to the first lines through the storage capacity  $C_s$ , potential changes  $C_s \cdot V_e(+)/\Sigma C$  and  $C_s \cdot V_e(-)/\Sigma C$  are generated in the pixel electrodes in the negative and positive directions, respectively and are added to the above mentioned potential change  $C_{gd} \cdot V_g / \Sigma C$ . If these potential changes are set so as to satisfy the following equation (A), dielectric anisotropy of liquid crystal and DC component induced through the capacity between the gate and the drain by the scanning signal are at least partially compensated for so as to eliminate causes of flicker, image sticking, etc., thereby resulting in high-quality display and rise of reliability of the display.

$$C_s \cdot V_e(+)/\Sigma C + C_{gd} \cdot V_g / \Sigma C = C_s \cdot V_e(-)/\Sigma C - C_{gd} \cdot V_g / \Sigma C = \Delta V^* \quad (A)$$

Supposing now that  $C_s$ ,  $C_{gd}$ ,  $\Sigma C$  and  $V_g$  have fixed values,  $V_e(+)$  and  $V_e(-)$  are not determined uniquely but satisfy the following relations (B) and (C).

$$(V_e(-) - V_e(+))/2 = C_{gd} \cdot V_g / C_s = \text{Constant} \quad (B)$$

$$(V_e(+)) - V_e(-)) = 2(\Sigma C / C_s) \Delta V^* = V_{\text{pp}} \quad (C)$$

When  $V_e(+)$  and  $V_e(-)$  are changed so as to satisfy the above equations (B) and (C), namely,  $\Delta V^*$  or  $V_{\text{pp}}$  is changed so as to satisfy the equations (B) and (C), VT characteristics of the display can be changed. Changing of  $\Delta V^*$  is equivalent to changing of  $V_{\text{pp}}$ .

Generally, in liquid crystal displays, VT characteristics change markedly according to angle for viewing the liquid crystal displays, especially, vertical angle for viewing the liquid crystal displays. When this change of VT characteristics according to viewing angle and change of VT characteristics due to shift of set  $\Delta V^*$  or  $V_{\text{pp}}$  are caused to eliminate each other, it becomes possible at a viewing point to uniform intensity of transmitted light over the whole screen.

In the present invention, since VT characteristics are changed gradually from the upper portion of the liquid crystal panel towards the lower portion of the liquid crystal panel, change of contrast or brightness due to difference of viewing angles for viewing the upper and lower portions of the liquid crystal panel can be lessened greatly.

Also in case the driving scheme is employed in which  $V_e(+)$ ,  $V_e(-)$  or  $\Delta V^*$  is given as a voltage value independent of each scanning signal line, DC electric field is not generated among potentials of the pixel electrode, the signal electrode and the counter electrode, so that DC voltage is not applied to liquid crystal

and thus, causes of flicker, image sticking, etc. can be eliminated, thereby resulting in higher operational reliability.

#### BRIEF DESCRIPTION OF THE DRAWINGS

This object and features of the present invention will become apparent from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings, in which:

Fig. 1 is a view explanatory of viewing angles ( $\theta$ ,  $\phi$ ) (already referred to);

Figs. 2a and 2b are graphs explanatory of dependence of VT characteristics on viewing angle (already referred to);

Fig. 3 is a schematic view of a liquid crystal display according to a first embodiment of the present invention;

Fig. 4 is a graph showing VT characteristics of the liquid crystal display of Fig. 3;

Fig. 5 is a schematic view showing an arrangement of a liquid crystal panel employed in a liquid crystal display according to a second embodiment of the present invention;

Fig. 6 is a circuit diagram explanatory of a principle of a liquid crystal display according to a third embodiment of the present invention;

Figs. 7a to 7f are views showing voltage wave forms of the liquid crystal display of Fig. 6;

Fig. 8 is a graph showing VT characteristics and effects of voltage in the liquid crystal display of Fig. 6;

Fig. 9 is a graph showing dependence of VT characteristics on viewing angle in the liquid crystal display of Fig. 6 driven by a known driving schema in which  $\Delta V^*$  of an identical value is given to all scanning lines;

Fig. 10 is a graph showing VT characteristics in which optimum  $Vt(+)$  and  $Vt(-)$  are set for various viewing angles in the liquid crystal display of Fig. 6;

Fig. 11 is a circuit diagram showing a basic structure of the liquid crystal display of Fig. 6;

Fig. 12 is a view showing voltage wave forms of signal lines in the liquid crystal display of Fig. 6;

Fig. 13 is a circuit diagram explanatory of a principle of a liquid crystal display according to a fourth embodiment of the present invention;

Figs. 14a and 14b are views showing voltage wave forms of the liquid crystal display of Fig. 13;

Fig. 15 is a circuit diagram showing a basic structure of the liquid crystal panel of Fig. 13;

Fig. 16 is a graph showing optimum  $V_{\text{pp}}$  for respective scanning signal lines in the liquid crystal panel of Fig. 13; and

Fig. 17 is a view showing layout of elements in an array substrate of a liquid crystal panel employed in a liquid crystal display according to a fifth embodiment of the present invention.

Before the description of the present invention proceeds, it is to be noted that like parts are designated by like reference numerals throughout several views of the accompanying drawings.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

When optical characteristics of a liquid crystal panel for different angles for viewing the liquid crystal panel are evaluated, a large liquid crystal panel having a display area of 250 mm x 320 mm is employed and VT characteristics obtained at the time when an upper portion of the liquid crystal panel is viewed at an angle  $\theta$  (Fig. 1) of 22.6° are compared with VT characteristics obtained at the time when a lower portion of the liquid crystal panel is viewed at an angle  $\theta$  of -22.6°.

Since effects of first and second embodiments of the present invention are not associated with active-matrix drive essentially, experiments in the first and second embodiments of the present invention are performed by using simple cells from a standpoint of their convenience.

A liquid crystal display according to the first embodiment of the present invention is described with reference to Figs. 3 and 4, hereinbelow. Initially, ITO (indium-tin-oxide) electrodes are provided on opposed surfaces of two glass substrates 27a each having an effective display area of 250 mm x 320 mm and 4.0 wt. % NMP solution of polyimide "PSI-2201" (brand name of Chisso Corporation of Japan) is coated on the opposed surfaces of the substrates 27a in spinning method so as to be cured into alignment layers at 200 °C for one hour. Subsequently, the alignment layers are subjected to rubbing at a twist angle of 90° such that a principal viewing angle direction is oriented towards an upper portion of a liquid crystal panel. Thereafter, the substrates 27a are bonded to each other through glass fibers of 4.0  $\mu\text{m}$  in diameter and then, liquid crystal "ZLI-1565" (brand name of E. Merck of Germany) is filled, as a liquid crystal layer 27b, in between the substrates 27a. Thus, a liquid crystal panel 27 is obtained.

As shown in Fig. 3, the liquid crystal display includes a backlight 21, an inverter 22, a transformer 23, a fan 24, a power source 25 for the backlight 21, a diffuser 26, the liquid crystal panel 27 and a driving circuit 28. The backlight 21, the inverter 22, the transformer 23, the fan 24, etc. are disposed so as to assemble a module such that upper and lower portion of the liquid crystal panel have temperatures of 60 °C and 20 °C, respectively. Subsequently, VT characteristics obtained at the time when the upper portion or the lower portion of the liquid crystal panel 27 is viewed on a normal passing through a center of the liquid crystal panel 27 and at a distance of 300 mm from the liquid crystal panel 27 are evaluated.

Fig. 4 shows results of measurements of the VT characteristics. At this time, measurement of contrast, i.e. ratio of brightness at the time of application of a voltage of 6V to brightness at the time of no application of the voltage has revealed that the upper and lower portions of the liquid crystal panel 27 have contrasts of 33 and 62, respectively.

On the other hand, when a module was designed as a comparative example in which a liquid crystal panel as a whole has a temperature of 20 °C, measurement of the contrast showed that upper and lower portions of the liquid crystal panel have contrasts of 12 and 60, respectively.

As will be apparent from the foregoing, in the liquid crystal panel in which the principal viewing angle direction is oriented towards the upper portion of the liquid crystal panel, when the module is designed such that the upper portion of the liquid crystal panel is set to a temperature higher than that of the lower portion of the liquid crystal panel, range of the viewing angle can be widened further.

In the present invention, predetermined temperature distribution is provided in the display screen of the liquid crystal panel, which is quite advantageous in also production process over a prior art liquid crystal panel in which temperature distribution in the display screen is made as uniform as possible.

Fig. 5 shows a liquid crystal panel 50 employed in a liquid crystal display according to a second embodiment of the present invention. Initially, ITO electrodes 32 and 32' are, respectively, provided on opposed surfaces of two glass substrates 31 and 31' each having an effective display area of 250 mm x 320 mm and polyimide solution "RN-753" (brand name of Nissan Chemical Industries, Ltd. of Japan) is coated on the opposed surfaces of the substrates 31 and 31' in spinning method so as to have a dried thickness of 600 Å as alignment layers 34 and 34', respectively. At this time, by controlling surface temperature of the hot stage, the polyimide solution for the alignment layers 34 and 34' is cured for one hour such that upper and lower portions of the substrates 31 and 31' have temperatures of 200 °C and 170 °C, respectively. Subsequently, the alignment layers 34 and 34' are subjected to rubbing at a twist angle of 90° such that a principal viewing angle direction is oriented towards an upper portion of the liquid crystal panel 50. Thereafter, the substrates 31 and 31' are bonded to each other through glass fibers of 4.5 μm in diameter by using sealing resin 33 and sealing resin 33' and then, liquid crystal "LIXON-5047" (brand name of Chisso Corporation) is filled, as a liquid crystal layer 40, in between the substrates 31 and 31'. As schematically shown in Fig. 5, liquid crystal molecules 35 of the liquid crystal layer 40 are aligned as shown schematically in Fig. 5 and thus, tilt angle of the liquid crystal molecules 35 is reduced from an upper portion of the liquid crystal panel 50 to a lower portion of the liquid crystal panel 50. Meanwhile, the glass fibers are not illustrated in Fig. 5. Thus, the liquid crystal panel 50 is obtained.

Then, in the same manner as in the first embodiment, contrast is measured when the upper and lower portions of the liquid crystal panel 50 are viewed on a normal passing through a center of the liquid crystal panel 50 and at a distance of 300 mm from the liquid crystal panel 50. Table 1 below shows results of the measurement.

Table 1

	Contrast	
	Present invention	Comp. example
Upper panel portion	30	16
Lower panel portion	50	50

As a comparative example, the alignment layers provided on the substrates are wholly cured at 170 °C such that the liquid crystal panel is obtained and then, contrast is measured as shown in Table 1 above.

Another experiment for measuring tilt angle has revealed that the alignment layers 34 and 34' of the present invention give tilt angles of 4.8° and 3.3° when cured at 200 °C for one hour and at 170 °C for one hour, respectively. In the second embodiment, it is apparently effective that tilt angle of the liquid crystal molecules 35 is reduced from the upper portion of the liquid crystal panel 50 to the lower portion of



the liquid crystal panel 50.

The present invention achieves such remarkable effects for practical use that dependence on viewing angle in the vertical direction of the liquid crystal panel 50 can be lessened greatly and viewing angle can be widened.

Meanwhile, a homogeneous cell provided with ITO electrodes and a liquid crystal layer having a thickness of 20  $\mu\text{m}$  is employed for measuring tilt angle of the liquid crystal molecules 35 and tilt angle of the liquid crystal molecules 35 is measured at 25  $^{\circ}\text{C}$  by crystal rotation method in a shortcircuiting state between the ITO electrodes.

Hereinbelow, third to five embodiments of the present invention directed to active-matrix liquid crystal displays are described. Concrete array structure and production method of the active-matrix liquid crystal displays have already been reported by, for example, E. Takeda et al. in IDRC (International Display Research Conference) '88, p156 (1988) and Proceedings of SID, p87 (1990).

In the third embodiment, polyimide solution "LX-5400" (brand name of Hitachi Chemical Co., Ltd. of Japan) is coated by spinning method on an array substrate and a color filter substrate having an effective display area of 250 mm x 320 mm so as to have a dried thickness of 600  $\text{\AA}$  as alignment layers. In the array substrate, 1036800 trio-pixels are provided on a glass substrate and each dot has a TFT element. Meanwhile, the color filter substrate has red, green and blue filters for the pixels, respectively. At this time, the polyimide solution is cured at 170  $^{\circ}\text{C}$ .

Subsequently, the alignment layers are subjected to rubbing at a twist angle of 90 $^{\circ}$  such that a principal viewing angle direction is oriented towards an upper portion of a liquid crystal panel. Thereafter, these substrates are bonded to each other through glass fibers of 4.0  $\mu\text{m}$  in diameter. Then, liquid crystal "ZLI-1565" (brand name of E. Merck) is filled, as a liquid crystal layer, in between the substrates. Thus, the liquid crystal panel is obtained.

Fig. 6 shows an equivalent circuit of display elements of the TFT active-matrix liquid crystal display of the present invention. Each display element has a TFT 3 at a junction of a scanning signal line 1 and an image signal line 2. As parasitic capacitors, the TFT 3 has gate-drain capacitor 4 having a capacity  $C_{gd}$ , a source-drain capacitor 5 having a capacity  $C_{sd}$  and a gate-source capacitor 6 having a capacity  $C_{gs}$ . In addition, a liquid crystal capacitor 7 having a capacity  $C_{lc}^*$  and a storage capacitor 8 having a capacity  $C_s$  are formulated intentionally.

As external driving voltages applied to the electrodes of the elements, a scanning signal  $V_g$  is supplied to the scanning signal line 1, an image signal voltage  $V_{sig}$  is supplied to the image signal line 2 and a first modulation signal  $V_e(+)$  or  $V_e(-)$  is supplied to one of electrodes of the storage capacitor 8 in accordance with polarity of the image signal inverted at an interval of one field. Meanwhile, a predetermined voltage is applied to a counter electrode of the liquid crystal capacitor 7 per field. In Fig. 6, through the parasitic capacitors and the capacitors formulated intentionally, influence of the driving voltages appears at a pixel electrode disposed at a point A. When the signals  $V_g$ ,  $V_e(+)$ ,  $V_e(-)$ ,  $V_t$  and  $V_{sig}$  which are defined as variable components of voltages associated with an  $n$ -th scanning line as shown in Figs. 7(a) to 7(d) are applied to the points in Fig. 6, respectively, potential changes  $\Delta V^{*+}$  and  $\Delta V^{*-}$  of the pixel electrode in even and odd fields through capacitive coupling are expressed by the following equations (1) and (2), respectively.

$$\Delta V^{*+} = (C_s \cdot V_e(+)) + C_{gd} \cdot V_g - C_{sd} \cdot V_{sig} / C_t \quad (1)$$

$$\Delta V^{*-} = (C_s \cdot V_e(-) - C_{gd} \cdot V_g - C_{sd} \cdot V_{sig}) / C_t \quad (2)$$

$$C_t = C_s + C_{gd} + C_{sd} + C_{lc}^*$$

The above equations (1) and (2) exclude potential variable component at the point A based on the conduction through the image signal line on turning on of the TFT. In the equations (1) and (2), the first term represents potential change caused by the first modulation signal, the second term represents potential change which is induced at the pixel electrode through the parasitic capacity  $C_{gd}$  of the TFT by the scanning signal  $V_g$  and the third term represents potential change which is induced at the pixel electrode through the parasitic capacity by the image signal voltage. The capacity  $C_{lc}^*$  is a capacity of liquid crystal, which changes under the influence of dielectric anisotropy in response to changes of alignment state of liquid crystal molecules due to magnitude of the signal voltage  $V_{sig}$ . Thus,  $C_{lc}^*$  and  $\Delta V^*$  correspond to a large capacity  $C_{lc}(h)$  and a small capacity  $C_{lc}(l)$  of liquid crystal, respectively. At this time, the capacity  $C_{gs}$  between the gate and the signal electrode is neglected not only because both the scanning signal line and the image signal line are driven by the low-impedance power source but because

coupling between the scanning signal line and the image signal line does not directly effect potential of the display electrode. If the potential changes  $\Delta V^+$  and  $\Delta V^-$  in the even and odd fields become equal to each other, DC voltage is not applied to liquid crystal and thus, symmetric AC drive can be performed. In this case, the following equation (3) is satisfied.

$$\begin{aligned} |C_s \cdot V_e(+) + C_{gd} \cdot V_g - C_{sd} \cdot V_{sig}| = \\ |C_s \cdot V_e(-) - C_{gd} \cdot V_g - C_{sd} \cdot V_{sig}| \quad (3) \end{aligned}$$

Since  $V_{sig}$  gives an inverted signal to each field, the third terms  $C_{sd} \cdot V_{sig}$  of the both sides in the equation (3) eliminate their effects to each other for the both field. Hence, the equation (3) can be simplified as follows.

$$(C_s \cdot V_e(+) + C_{gd} \cdot V_g) = (C_s \cdot V_e(-) - C_{gd} \cdot V_g) = \Delta V^* \quad (4)$$

This equation (4) is changed to the following equation (5).

$$(V_e(-) - V_e(+)) = 2C_{gd} \cdot V_g / C_s = V_{epp} \quad (5)$$

The first point to be noted is that the positive and negative potentials  $\Delta V^*$  induced at the pixel electrode for the even and off fields can be made equal to each other relative to the counter electrode regardless of the capacity of liquid crystal. Therefore, an identical voltage of positive and negative polarities is applied to liquid crystal and thus, flicker is substantially reduced.

The second point to be noted is that  $Clc^*$  does not appear in the equations (3) and (4). Namely, if liquid crystal is driven under the conditions satisfying the equations (3) and (4), effects of dielectric anisotropy of liquid crystal disappear and DC voltage resulting from  $Clc^*$  is not generated in the display.

Meanwhile, the third point to be noted is that under the driving conditions satisfying the equations (3) and (4), the scanning signal  $V_g$  is capable of eliminating to zero, the DC potential induced between the image signal line and the display electrode through the parasitic capacity  $C_{gd}$ . Meanwhile, in the driving scheme of the present invention, since signals of positive and negative polarities for the both fields are applied to potential of the counter electrode, DC electric field is not generated among potentials of the pixel electrode, the signal electrode and the counter electrode. Thus, the driving scheme of the present invention does not apply DC voltage to liquid crystal, thereby resulting in higher operational reliability.

The fourth point to be noted is that the conditional equations (3) and (4) include the two voltage parameters  $V_e(+)$  and  $V_e(-)$  which can be arbitrarily set at display. Therefore, if the parameters  $V_e(+)$  and  $V_e(-)$  are controlled in accordance with the equations (3) and (4), the potential change  $\Delta V^*$  appearing at the pixel electrode can be set to an arbitrary value. By changing this  $\Delta V^*$ , VT characteristics of the display can be changed and thus, the object of the present invention, i.e., improvement of dependence on viewing angle can be achieved. Meanwhile, when  $\Delta V^*$  is not less than a threshold voltage of liquid crystal,  $V_{sig}$  can be reduced, thus resulting in saving of electric power. On the other hand,  $V_g$  is a semi-fixed constant determined by the driving conditions but effects of  $V_g$  can be corrected by  $V_e(+)$  and  $V_e(-)$ . Meanwhile,  $V_{sig}$  is display data itself and varies between a maximum and a minimum arbitrarily.

Figs. 7e and 7f depict voltage changes at the pixel electrode of the point A in Fig. 6 when the driving signals  $V_g$  and  $V_{sig}$  and the modulation signal  $V_e$  have been applied to the electrodes of the display elements of Fig. 6. For example, in case the scanning signal  $V_g$  is inputted at  $T = T_1$  when  $V_{sig}$  stands at  $V_s(h)$  in the odd field as shown by the solid line of Fig. 7d, the TFT is conducted so as to charge the point A until the potential  $V_a$  of the point A becomes identical with the potential  $V_s(h)$ . Before the TFT is turned off at  $T = T_2$ , desirably, between  $T_1$  and  $T_2$  during which the TFT is in conductive state, the signal  $V_e(-)$  is imparted to  $V_e$  in the negative direction. Subsequently, when the scanning signal disappears, this change of  $V_g$  appears as potential variations at the point A through  $C_{gd}$ . Furthermore, when  $V_e$  has changed by  $V_e(-)$  in the negative direction at  $T = T_4$  through a lag time  $\tau_d$ , this influence appears as displacement of the potential  $V_a$  in the positive direction as shown. Subsequently, when  $V_{sig}$  has changed from  $V_s(h)$  to  $V_s(1)$  at  $T = T_5$ , potential variation at the point A appears similarly. In Figs. 7e and 7f, this capacitive coupling component is included in  $\Delta V^*$ .

Thereafter, when the scanning signal has been inputted in the even field, the TFT charges the point A to the low level  $V_s(1)$  of  $V_{sig}$ . When the TFT has been turned off, the capacitive coupling potential  $\Delta V^*$  appears in the same manner as described above. In case  $V_{sig}$  is at high level and  $V_e$  is at low level or to the contrary,  $V_{sig}$  is at low level and  $V_e$  is at high level when the TFT is turned off as described above, effective applied voltage amplitude  $V_{eff}$  for liquid crystal is substantially equal to  $(2\Delta V^* + V_{sigpp})$  relative

to image signal amplitude  $V_{sigpp}$  as shown in the case where  $V_e$  varies after the TFT has been turned off. As a result,  $V_e$  and  $V_{sig}$  overlap each other. In other words, output amplitude of image signal output IC can be reduced by  $2\Delta V^*$ . The above mentioned phase relation between  $V_e$  and  $V_{sig}$  is referred to as "opposite phase". On the other hand, phase relation which  $V_{sig}$  has for the modulation signal  $V_e$  as shown by dotted line in Fig. 7d is referred to as "in-phase". Effective applied voltage amplitude at the point A is substantially equal to  $(2\Delta V^* - V_{sigpp})$ , so that  $\Delta V^*$  and  $V_{sig}$  partially eliminate each other.

Fig. 8 show VT characteristics of liquid crystal and an example of voltage range for controlling transmitted light by  $\Delta V^*$  and  $V_{sig}$ . The voltage range for changing transmitted light of liquid crystal is from a threshold voltage  $V_{th}$  to a saturation voltage  $V_{max}$  in liquid crystal. When  $\Delta V^*$  is so set as to be not less than  $V_{th}$ , a necessary maximum signal voltage is  $(V_{max} - V_{th})$  if phase control is not performed. If amplitude and phase of signal voltage are controlled with setting the applied voltage based on  $\Delta V^*$  to  $V_{ct}$ , the necessary maximum signal voltage can be reduced to about  $\{(V_{max} - V_{th})/2\}$ .

In this embodiment, a case is given in which a liquid crystal display having a height of about 25 cm is viewed orthogonally at a distance of 40 cm from a center of the liquid crystal display. At this time, when upper and lower ends of the display are viewed, an angle of about  $17^\circ$  is formed vertically for each of the upper and lower ends of the display.

Fig. 9 shows relation between input signal voltage and transmittance characteristics through change of viewing angle. In case  $\Delta V^*$  of an identical value is given to all the scanning lines, VT characteristics change greatly according to viewing angle.

In the liquid crystal display of this embodiment, principal viewing angle direction is set towards the upper portion of the liquid crystal panel. Thus, when the display screen is viewed from above, VT characteristics shift to low-voltage side of input voltage. On the contrary, when the display screen is viewed from below, VT characteristics shift to high-voltage side of input voltage.

Thus, when  $\Delta V^*$  which gives, in viewing angles corresponding to the respective scanning lines, VT characteristics most approximate to those of a viewing point orthogonal to the liquid crystal display is given to each scanning line, VT characteristics at the respective viewing angles come close to each other as shown in Fig. 10. As a result, transmitted light intensity of the whole display screen becomes uniform at a viewing point orthogonal to the liquid crystal display and thus, the object of the present invention, i.e., improvement of dependence on viewing angle can be achieved. Namely, by utilizing such a property that VT characteristics shift to high-voltage and low-voltage sides of input voltage when  $\Delta V^*$  is reduced and increased, respectively,  $\Delta V^*$  which gives, in viewing angles corresponding to the respective scanning lines from a viewing point, VT characteristics most approximated to those at the center of the display screen is given to each scanning line. In this embodiment,  $\Delta V^*$  is gradually reduced as a point on the display screen is displaced downwardly. At this time, difference between  $V^*$  at the upper portion of the screen and  $\Delta V^*$  at the lower portion of the screen is about 1.5 V.

Fig. 11 shows a circuit of the liquid crystal display according to the third embodiment of the present invention. The circuit includes a scanning driving circuit 9, an image signal driving circuit 10, a first modulation circuit 11, a second modulation circuit 12, scanning signal lines 13a to 13z, image signal lines 14a to 14z, common electrodes 15a to 15z each having a storage capacity  $C_s$  and counter electrodes 16a to 16z of liquid crystal. In this embodiment, since the storage capacity and the counter electrode are separately formed on each scanning signal line as described above, the first modulation signal is also applied to each corresponding scanning signal line.

Fig. 12 is a timing chart of the scanning signal and the modulation signal and depicts the scanning signal and the modulation signal for the  $n$ -th and  $(n+1)$ -th scanning signal lines. Relations of the modulation signal and the image signal versus  $\Delta V^*$  and  $V_{sig}$  are substantially equal to those of Figs. 7a to 7f. Namely, polarities of the image signal and the modulation signal are inverted per field. In Fig. 12, different value are imparted to  $\Delta V^*$ , i.e.  $V_{pp}$  for the  $n$ -th scanning signal line and that for the  $(n+1)$ -th scanning signal line. This active-matrix liquid crystal display can be driven with less flicker in the whole range from white to black by setting output amplitude of the signal voltage to  $3V_{pp}$  and is capable of performing display having excellent contrast. Furthermore, DC component between the electrodes scarcely exists and reliability of liquid crystal is excellent for a long time. Hereinbelow, other embodiments are described in which wide viewing angle is achieved by driving scheme.

Except for that an array substrate in which the first signal line acts also as the scanning signal line is employed, an active-matrix liquid crystal display according to the fourth embodiment of the present invention is the same as that of the third embodiment. Fig. 13 shows an equivalent circuit of display elements of the TFT active-matrix liquid crystal display of the present invention. The electric circuit includes an  $n$ -th scanning signal line 1', an  $(n+1)$ -th scanning signal line, an image signal line 2 and a TFT 3. As parasitic capacities, the TFT 3 includes a gate-drain capacitor 4 having a capacity  $C_{gd}$ , a source-drain

capacitor 5 having a capacity  $C_{sd}$  and a gate-source capacitor 6 having a capacity  $C_{gs}$ . Furthermore, a liquid crystal capacitor 7 having a capacity  $C_{lc}$  and a storage capacitor 8 having a capacity  $C_s$  are formulated intentionally.

As external driving voltages applied to the electrodes of the elements, a scanning signal  $V_g(n)$  is supplied to the  $n$ -th scanning signal line 1', a scanning signal  $V_g(n+1)$  is supplied to the  $(n+1)$ -th scanning signal line 1" and the image signal voltage  $V_{sig}$  is supplied to the image signal line 2. Meanwhile, a predetermined voltage is applied to a counter electrode of the liquid crystal capacitor 7. Influence of the driving voltages appears at a pixel electrode disposed at a point A through the parasitic capacitors and the capacitors formulated intentionally. When the signals  $V_g$ ,  $V_e(+)$ ,  $V_e(-)$ ,  $V_t$  and  $V_{sig}$  which are defined as variable components of voltages associated with an  $n$ -th scanning line as shown in Figs. 14a and 14b are applied to the points in Fig. 13, respectively, potential changes  $\Delta V^+$  and  $\Delta V^-$  of the pixel electrode in even and odd fields through capacitive coupling are, respectively, expressed by the equations (1) and (2) referred to earlier. Potential variable component at the point A based on the conduction through the image signal line on turning on of the TFT is excluded from the equations (1) and (2). Therefore, in the same manner as in the third embodiment, viewing angle can be widened by changing  $\Delta V^*$  for each scanning line.

Fig. 15 shows a circuit of the liquid crystal display according to the fourth embodiment of the present invention. The circuit includes a scanning signal and modulation signal driving circuit 17, the image signal driving circuit 10, a counter electrode driving circuit 18, the scanning signal lines 13a to 13z, the image signal lines 14a to 14z and the counter electrodes 16a to 16z of liquid crystal. In this embodiment, since the storage capacitor is separately formed on each scanning signal line as described above, the modulation signal is applied to each corresponding scanning signal line.

Fig. 16 shows an optimum  $V_{epp}$  for each scanning signal line. In Fig. 16, supposing that character A denotes a constant,  $V_{epp}(n)$  for the  $n$ -th scanning signal line and  $V_{epp}(n+1)$  for the  $(n+1)$ -th scanning signal line have the following relation.

$$|V_{epp}(n) - V_{epp}(n+1)| = A$$

By performing drive in which optimum  $V_{epp}$  is added to each scanning signal line in this way, the liquid crystal display lessens dependence on viewing angle in the vertical direction of the liquid crystal panel. At this time, difference between  $V_{epp}$  at the upper portion of the display screen and that at the lower portion of the display screen is about 3.5 V.

Finally, Fig. 17 shows layout of an array substrate employed in a liquid crystal panel of a liquid crystal display according to a fifth embodiment of the present invention. The array substrate includes a source electrode (image signal line) 61, a gate electrode (scanning signal line) 62, a storage capacitor 63, contact windows 64 and 67, a pixel electrode 65, a drain electrode 66 and a TFT 68. In this embodiment, area of the storage capacitor 63 is changed from the upper portion of the liquid crystal panel towards the lower portion of the liquid crystal panel such that the storage capacitor has a capacity five times a liquid crystal capacity and a capacity equal to the liquid crystal capacity at the upper portion and the lower portion of the liquid crystal panel, respectively. Fig. 17 explains capacity of the storage capacitor 63 gradually changes in the array substrate from the upper portion of the liquid crystal panel towards the lower portion of the liquid crystal panel. The number of pixels of the array substrate employed in this embodiment is different from that of Fig. 17.

A concrete production method of the liquid crystal panel is described, hereinbelow. Polyimide solution "LX-5400" (brand name of Hitachi Chemical Co., Ltd.) is coated by spinning method on an array substrate and a color filter substrate having an effective display area of 250 mm x 320 mm so as to have a dried thickness of 600 Å as alignment layers. In the array substrate, 1036800 trio-pixels are provided on a glass substrate and each dot has a TFT element. Meanwhile, the color filter substrate has red, green and blue pixels for the pixels, respectively. At this time, the polyimide solution is cured at 170 °C.

Subsequently, the alignment layers are subjected to rubbing at a twist angle of 90° such that a principal viewing angle direction is oriented towards the upper portion of the liquid crystal panel. Thereafter, these substrates are bonded to each other through glass fibers of 4.0 μm in diameter. Then, liquid crystal "ZLI-1565" (brand name of E. Merck) is filled, as a liquid crystal layer, in between the substrates. Thus, the liquid crystal panel is obtained.

When contrast is measured by viewing the upper and lower portions of the liquid crystal panel at a distance of 300 mm on a normal passing through the center of the liquid crystal panel while the modulation signal amplitude  $V_{epp}$  is kept constant, the upper portion of the liquid crystal panel has a contrast of 37 and the lower portion of the liquid crystal panel has a contrast of 62.

As will be seen from the foregoing, since capacity of the storage capacitor is reduced from the upper portion of the liquid crystal panel towards the lower portion of the liquid crystal panel, differences of contrast and transmittance characteristics due to change of angle for viewing the liquid crystal panel can be improved remarkably.

This is clear also from the equation (C). By changing the capacity  $C_s$  of the storage capacity gradually from the upper portion of the liquid crystal panel towards the lower portion of the liquid crystal panel even when the modulation signal amplitude is constant, satisfactory effects of improvement of viewing angle can be achieved.

## 10 Claims

1. An active-matrix liquid crystal display including a liquid crystal panel (27) in which temperature changes gradually from an upper portion of the liquid crystal panel (27) towards a lower portion of the liquid crystal panel (27).

2. An active-matrix liquid crystal display including a liquid crystal panel (50) having a liquid crystal layer (40) in which tilt angle of liquid crystal molecules (35) changes gradually from an upper portion of the liquid crystal panel (50) towards a lower portion of the liquid crystal panel (50).

3. An active-matrix liquid crystal display comprising:

a plurality of first lines (15a-15z);

a plurality of pixel electrodes (7) which are connected to the first lines (15a-15z) through capacitors so as to be disposed in a pattern of a matrix;

an image signal line (14a-14z);

a scanning signal line (13a-13z);

a switching element (3) which is electrically connected to the image signal line (14a-14z) and the scanning signal line (13a-13z) and is connected to each of the pixel electrodes (7);

a counter electrode ( $V_t$ ); and

liquid crystal (7) which is held between each of the pixel electrodes (7) and the counter electrode ( $V_t$ ) and is subjected to AC drive;

wherein when during an ON period of the switching element (3), an image signal voltage obtained by inverting polarity of a signal voltage is supplied to the pixel electrodes (7) per field of a display screen and during an OFF period of the switching element (3), a first modulation signal having a polarity opposite to that of the image signal voltage is supplied to the first lines (15a-15z) per field of the display screen, potential of the pixel electrodes (7) is changed such that a voltage obtained by adding a change of the potential of the pixel electrodes (7) and the image signal voltage to each other is applied to the liquid crystal (7);

wherein the first modulation signals supplied to the first lines (15a-15z), respectively are different from one another.

4. An active-matrix liquid crystal display comprising:

a plurality of first lines (15a-15z);

a plurality of pixel electrodes (7) which are connected to the first lines (15a-15z) through capacitors so as to be disposed in a pattern of a matrix;

an image signal line (14a-14z);

a scanning signal line (13a-13z);

a switching element (3) which is electrically connected to the image signal line (14a-14z) and the scanning signal line (13a-13z) and is connected to each of the pixel electrodes (7);

a counter electrode ( $V_t$ ); and

liquid crystal (7) which is held between each of the pixel electrodes (7) and the counter electrode ( $V_t$ ) and is subjected to AC drive;

wherein when during an ON period of the switching element (3), an image signal voltage obtained by inverting polarity of a signal voltage is supplied to the pixel electrodes (7) per field of a display screen and during an OFF period of the switching element (3), a first modulation signal having a polarity opposite to that of the image signal voltage is supplied to the first lines (15a-15z) per field of the display screen, potential of the pixel electrodes (7) is changed such that a voltage obtained by eliminating a change of the potential of the pixel electrodes (7) and the image signal voltage to each other is applied to the liquid crystal (7);

wherein the first modulation signals supplied to the first lines (15a-15z), respectively are different from one another.

- 5 5. An active-matrix liquid crystal display as claimed in Claim 3, wherein the image signal voltage is obtained by inverting the polarity of the signal voltage per scanning line of the display screen and the polarity of the first modulation signal is inverted per scanning line.
6. An active-matrix liquid crystal display as claimed in Claim 4, wherein the image signal voltage is obtained by inverting the polarity of the signal voltage per scanning line of the display screen and the polarity of the first modulation signal is inverted per scanning line.
7. An active-matrix liquid crystal display as claimed in Claim 5, wherein the first modulation signals ( $V_e(+)$ ,  $V_e(-)$ ) of the opposite polarities have different absolute values.
- 15 8. An active-matrix liquid crystal display as claimed in Claim 6, wherein the first modulation signals ( $V_e(+)$ ,  $V_e(-)$ ) of the opposite polarities have different absolute values.
9. An active-matrix liquid crystal display as claimed in Claim 7, wherein prior to lapse of the ON period of the switching element (3), a portion of a potential of the first modulation signal is changed.
- 20 10. An active-matrix liquid crystal display as claimed in Claim 8, wherein prior to lapse of the ON period of the switching element (3), a portion of a potential of the first modulation signal is changed.

- 25 11. An active-matrix liquid crystal display as claimed in Claim 7, wherein the switching element is a thin film transistor (3),

wherein supposing that  $V_e(+)$  and  $V_e(-)$  denote the first modulation signals of the opposite polarities, respectively,  $V_g$  denotes a potential change of a scanning signal,  $C_s$  denotes a storage capacity,  $C_{gd}$  denotes a capacity between a gate and a drain,  $C_{sd}$  denotes a capacity between a source and a drain and  $\Sigma C$  denotes an overall electrostatic capacity per pixel, potential changes  $C_s \cdot V_e(+)/\Sigma C$  and  $C_s \cdot V_e(-)/\Sigma C$  of the pixel electrodes (7) by the first modulation signals and potential change  $C_{gd} \cdot V_g/\Sigma C$  of the pixel electrodes (7) due to the potential change of the scanning signal have the following relation:

$$C_s \cdot V_e(+)/\Sigma C + C_{gd} \cdot V_g/\Sigma C = C_s \cdot V_e(-)/\Sigma C - C_{gd} \cdot V_g/\Sigma C = \Delta V^*$$

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where  $\Delta V^*$  has a value not less than a threshold voltage of the liquid crystal (7).

- 40 12. An active-matrix liquid crystal display as claimed in Claim 8, wherein the switching element is a thin film transistor (3),

wherein supposing that  $V_e(+)$  and  $V_e(-)$  denote the first modulation signals of the opposite polarities, respectively,  $V_g$  denotes a potential change of a scanning signal,  $C_s$  denotes a storage capacity,  $C_{gd}$  denotes a capacity between a gate and a drain,  $C_{sd}$  denotes a capacity between a source and a drain and  $\Sigma C$  denotes an overall electrostatic capacity per pixel, potential changes  $C_s \cdot V_e(+)/\Sigma C$  and  $C_s \cdot V_e(-)/\Sigma C$  of the pixel electrodes (7) by the first modulation signals and potential change  $C_{gd} \cdot V_g/\Sigma C$  of the pixel electrodes (7) due to the potential change of the scanning signal have the following relation:

$$C_s \cdot V_e(+)/\Sigma C + C_{gd} \cdot V_g/\Sigma C = C_s \cdot V_e(-)/\Sigma C - C_{gd} \cdot V_g/\Sigma C = \Delta V^*$$

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where  $\Delta V^*$  has a value not less than a threshold voltage of the liquid crystal (7).

- 55 13. An active-matrix liquid crystal display as claimed in Claim 7, wherein the scanning signal line (13a-13z) acts also as each of the first lines (15a-15z) and the first modulation signal in addition to a scanning signal is applied to the scanning signal line (13a-13z).

14. An active-matrix liquid crystal display as claimed in Claim 8, wherein the scanning signal line (13a-13z) acts also as each of the first lines (15a-15z) and the first modulation signal in addition to a scanning signal is applied to the scanning signal line (13a-13z).

15. An active-matrix liquid crystal display as claimed in Claim 13, wherein the first modulation signal  $V_e(+)$  of one polarity is supplied to the scanning signal line (13 a-13z) during the OFF period of the switching element (3) in an odd field and the first modulation signal  $V_e(-)$  of the other polarity is supplied to the scanning signal line (13a-13z) during the OFF period of the switching element (3) in an even field so as to change the potential of the pixel electrodes (7),

wherein supposing that a modulation signal amplitude  $V_{\text{epp}}$  is defined as  $V_{\text{epp}} = |V_e(+)-V_e(-)|$ , a modulation signal amplitude  $V_{\text{epp}}(n)$  for an  $n$ -th scanning signal line (13a-13z) and a modulation signal amplitude  $V_{\text{epp}}(n+1)$  for an  $(n+1)$ -th scanning signal line (13a-13z) have the following relation:

$$V_{\text{epp}}(n) \leq V_{\text{epp}}(n+1)$$

where character  $n$  denotes an arbitrary natural number.

16. An active-matrix liquid crystal display as claimed in Claim 13, wherein the first modulation signal  $V_e(+)$  of one polarity is supplied to the scanning signal line (13 a-13z) during the OFF period of the switching element (3) in an odd field and the first modulation signal  $V_e(-)$  of the other polarity is supplied to the scanning signal line (13a-13z) during the OFF period of the switching element (3) in an even field so as to change the potential of the pixel electrodes (7),

wherein supposing that a modulation signal amplitude  $V_{\text{epp}}$  is defined as  $V_{\text{epp}} = |V_e(+)-V_e(-)|$ , a modulation signal amplitude  $V_{\text{epp}}(n)$  for an  $n$ -th scanning signal line (13a-13z) and a modulation signal amplitude  $V_{\text{epp}}(n+1)$  for an  $(n+1)$ -th scanning signal line (13a-13z) have the following relation:

$$V_{\text{epp}}(n) \geq V_{\text{epp}}(n+1)$$

where character  $n$  denotes an arbitrary natural number.

17. An active-matrix liquid crystal display as claimed in Claim 15, wherein the modulation signal amplitude  $V_{\text{epp}}(n)$  for the  $n$ -th scanning signal line (13a-13z) and the modulation signal amplitude  $V_{\text{epp}}(n+1)$  for the  $(n+1)$ -th scanning signal line (13a-13z) have the following relation:

$$|V_{\text{epp}}(n) - V_{\text{epp}}(n+1)| = A$$

where character  $A$  denotes a constant.

18. An active-matrix liquid crystal display as claimed in Claim 16, wherein the modulation signal amplitude  $V_{\text{epp}}(n)$  for the  $n$ -th scanning signal line (13a-13z) and the modulation signal amplitude  $V_{\text{epp}}(n+1)$  for the  $(n+1)$ -th scanning signal line (13a-13z) have the following relation:

$$|V_{\text{epp}}(n) - V_{\text{epp}}(n+1)| = A$$

where character  $A$  denotes a constant.

19. An active-matrix liquid crystal display comprising:

a plurality of first lines;  
a plurality of pixel electrodes (65) which are connected to the first lines through capacitors so as to be disposed in a pattern of a matrix;  
an image signal line (61);  
a scanning signal line (62);  
a switching element (68) which is electrically connected to the image signal line (61) and the scanning signal line (62) and is connected to each of the pixel electrodes (65);  
a counter electrode; and  
liquid crystal which is held between each of the pixel electrodes (65) and the counter electrode and is subjected to AC drive;

wherein when during an ON period of the switching element (68), an image signal voltage obtained by inverting polarity of a signal voltage is supplied to the pixel electrodes (65) per field of a display screen and during an OFF period of the switching element (68), a first modulation signal having a polarity opposite to that of the image signal voltage is supplied to the first lines per field of the display screen, potential of the pixel electrodes (65) is changed such that a voltage obtained by adding a

change of the potential of the pixel electrodes (65) and the image signal voltage to each other is applied to the liquid crystal;

wherein magnitude of storage capacity (63) changes gradually from an upper portion of a liquid crystal panel towards a lower portion of the liquid crystal panel.

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20. An active-matrix liquid crystal display comprising:

a plurality of first lines;

a plurality of pixel electrodes (65) which are connected to the first lines through capacitors so as to be disposed in a pattern of a matrix;

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an image signal line (61);

a scanning signal line (62);

a switching element (68) which is electrically connected to the image signal line (61) and the scanning signal line (62) and is connected to each of the pixel electrodes (65);

a counter electrode; and

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liquid crystal which is held between each of the pixel electrodes (65) and the counter electrode and is subjected to AC drive;

wherein when during an ON period of the switching element (68), an image signal voltage obtained by inverting polarity of a signal voltage is supplied to the pixel electrodes (65) per field of a display screen and during an OFF period of the switching element (68), a first modulation signal having a polarity opposite to that of the image signal voltage is supplied to the first lines per field of the display screen, potential of the pixel electrodes (65) is changed such that a voltage obtained by eliminating change of the potential of the pixel electrodes (65) and the image signal voltage to each other is applied to the liquid crystal;

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wherein magnitude of storage capacity (63) changes gradually from an upper portion of a liquid crystal panel towards a lower portion of the liquid crystal panel.

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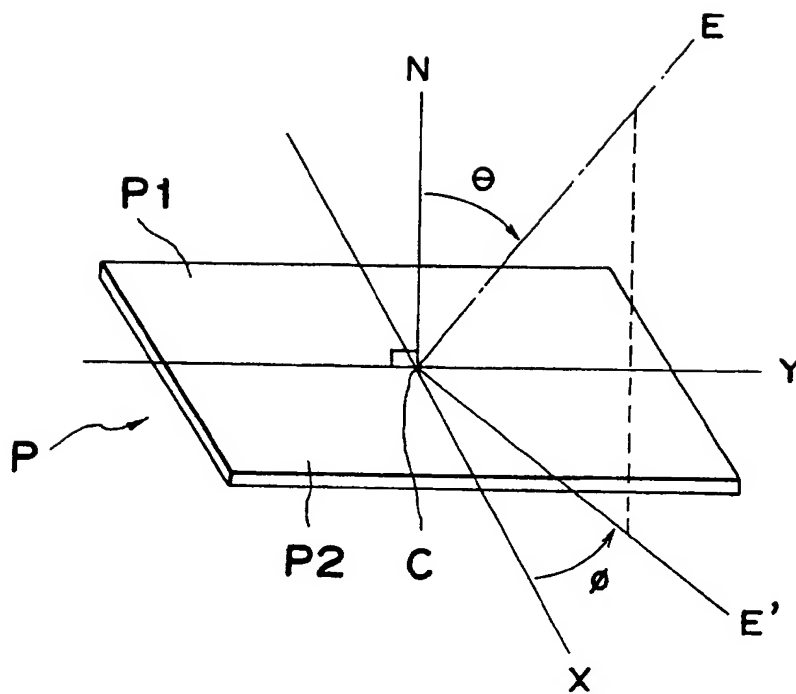
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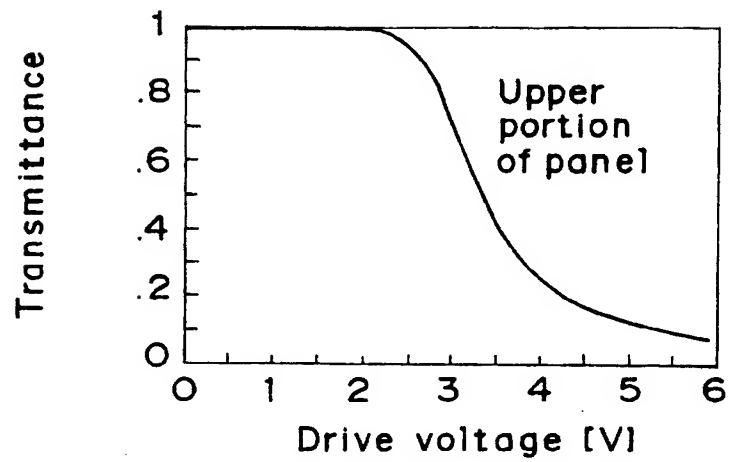
*Fig. 1*



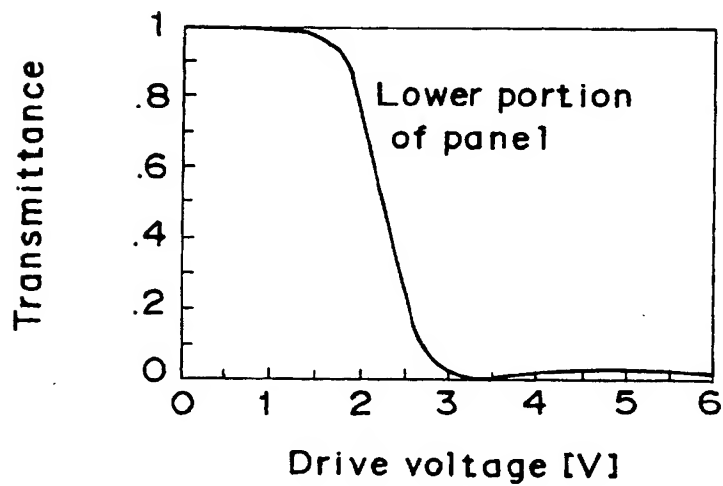
$$0^\circ \leq \phi \leq 90^\circ \quad 270^\circ \leq \phi \leq 360^\circ : \theta \geq 0$$

$$90^\circ \leq \phi \leq 270^\circ : \theta \leq 0$$

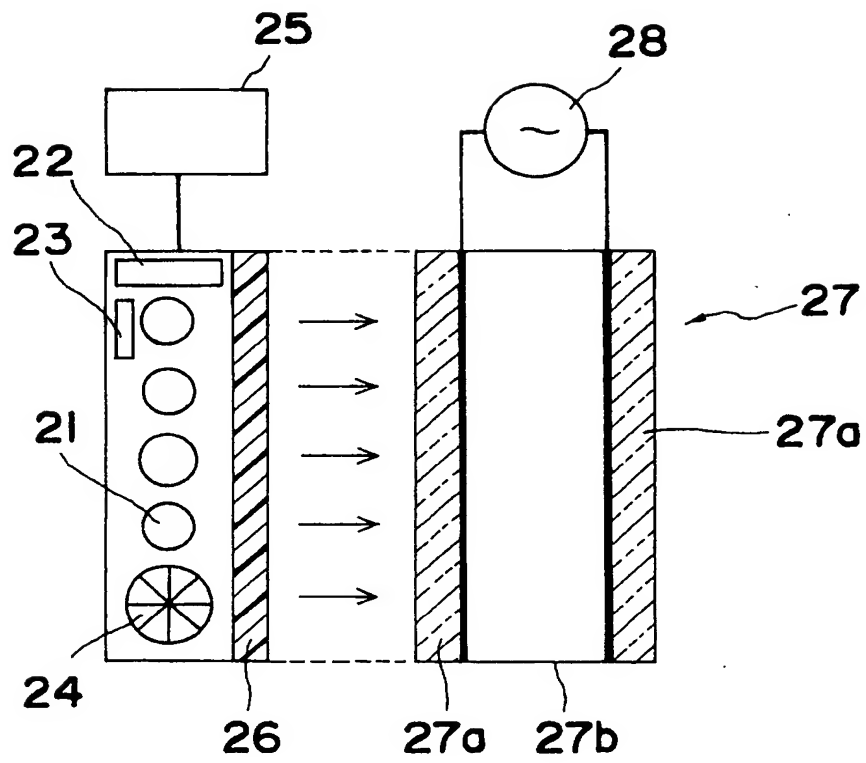
*Fig. 2a*



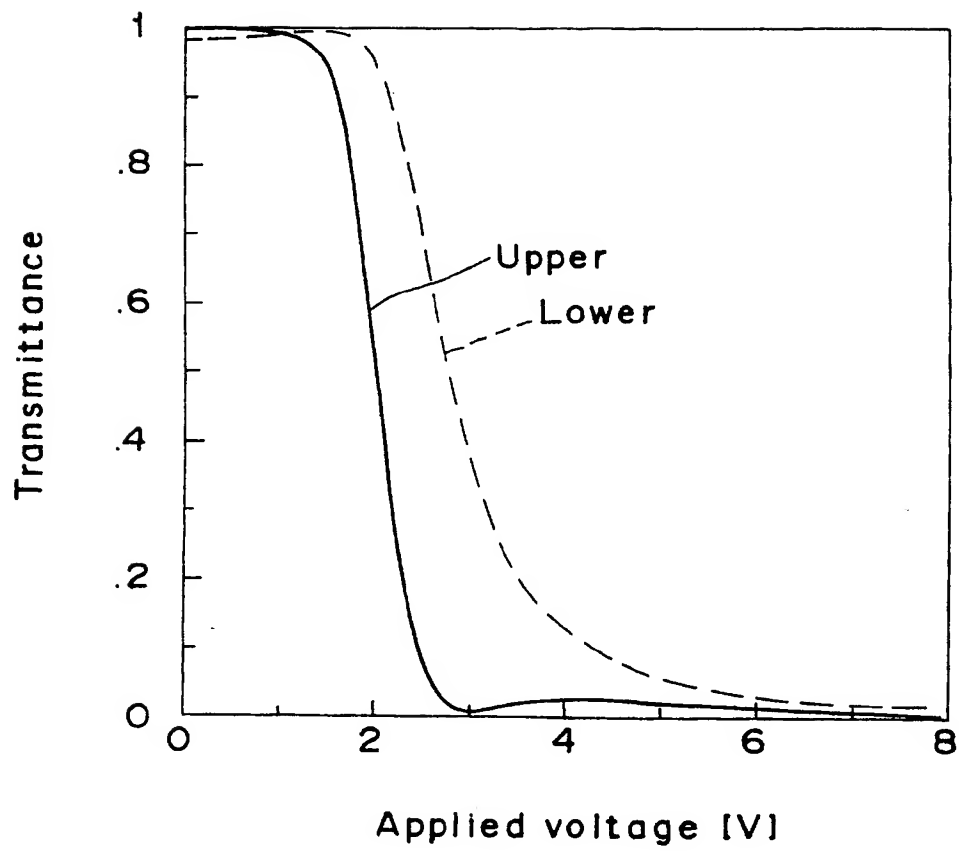
*Fig. 2b*



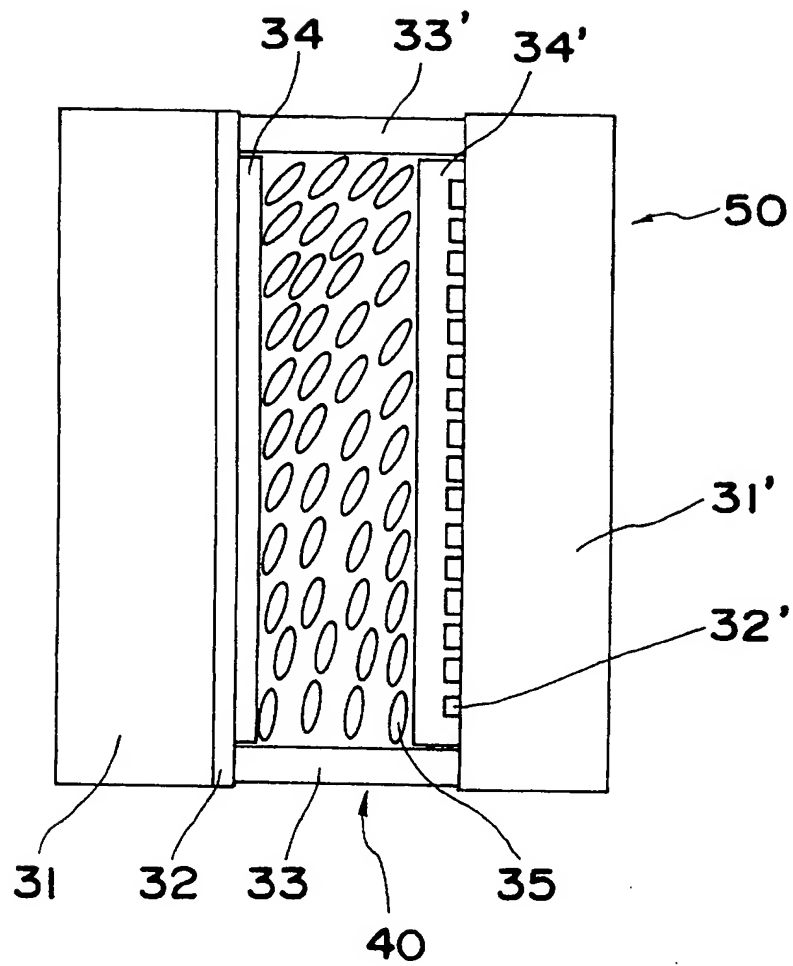
*Fig. 3*



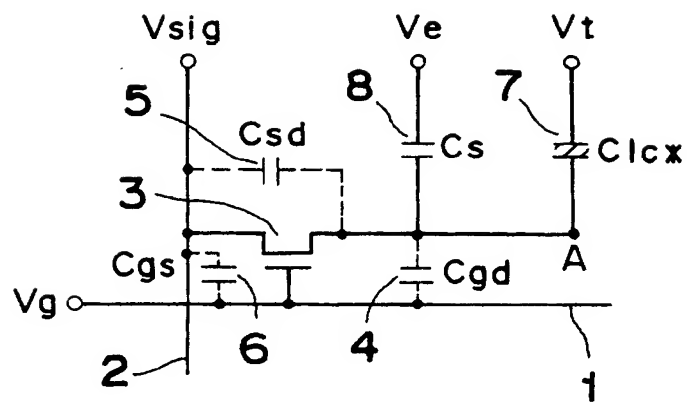
*Fig. 4*

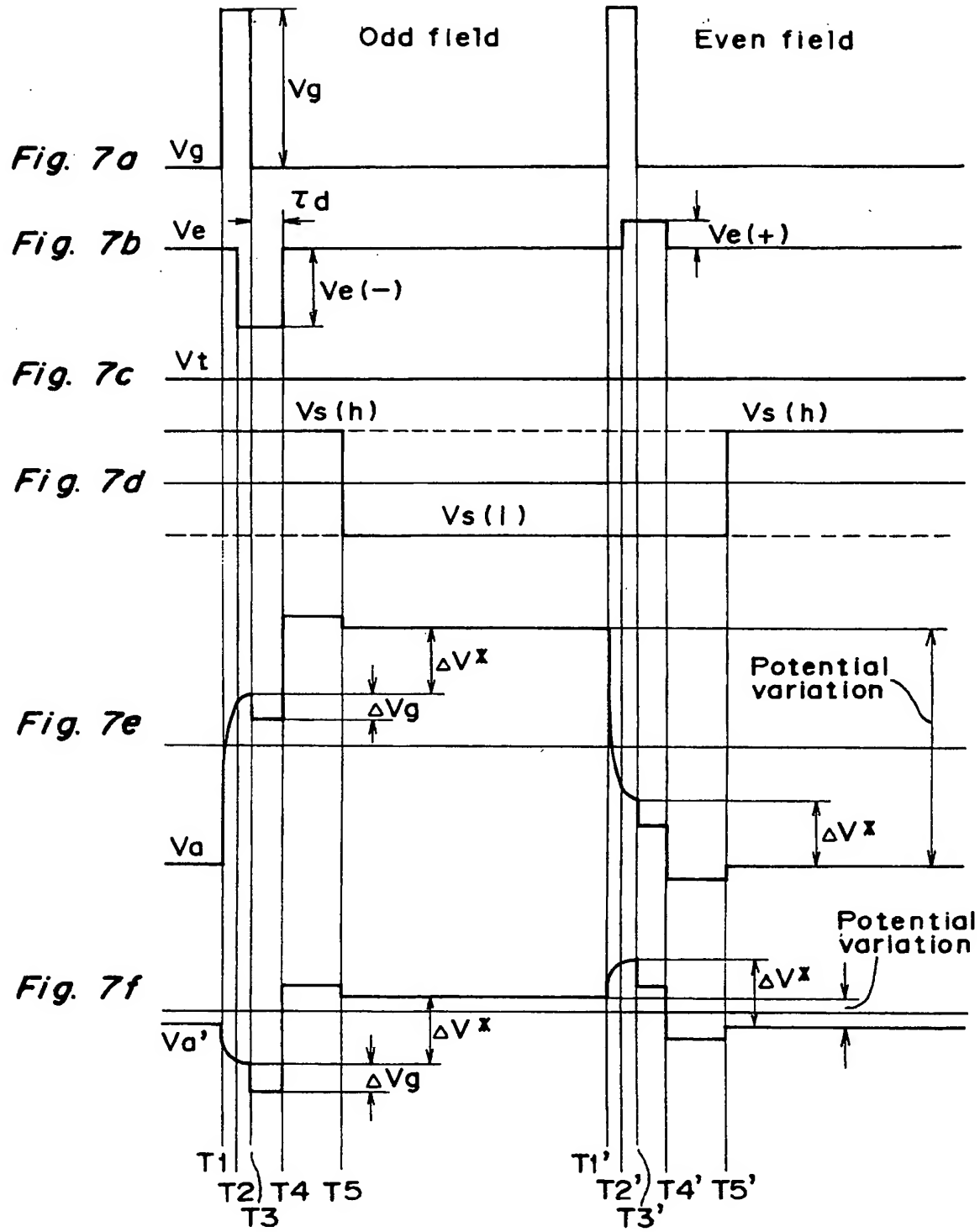


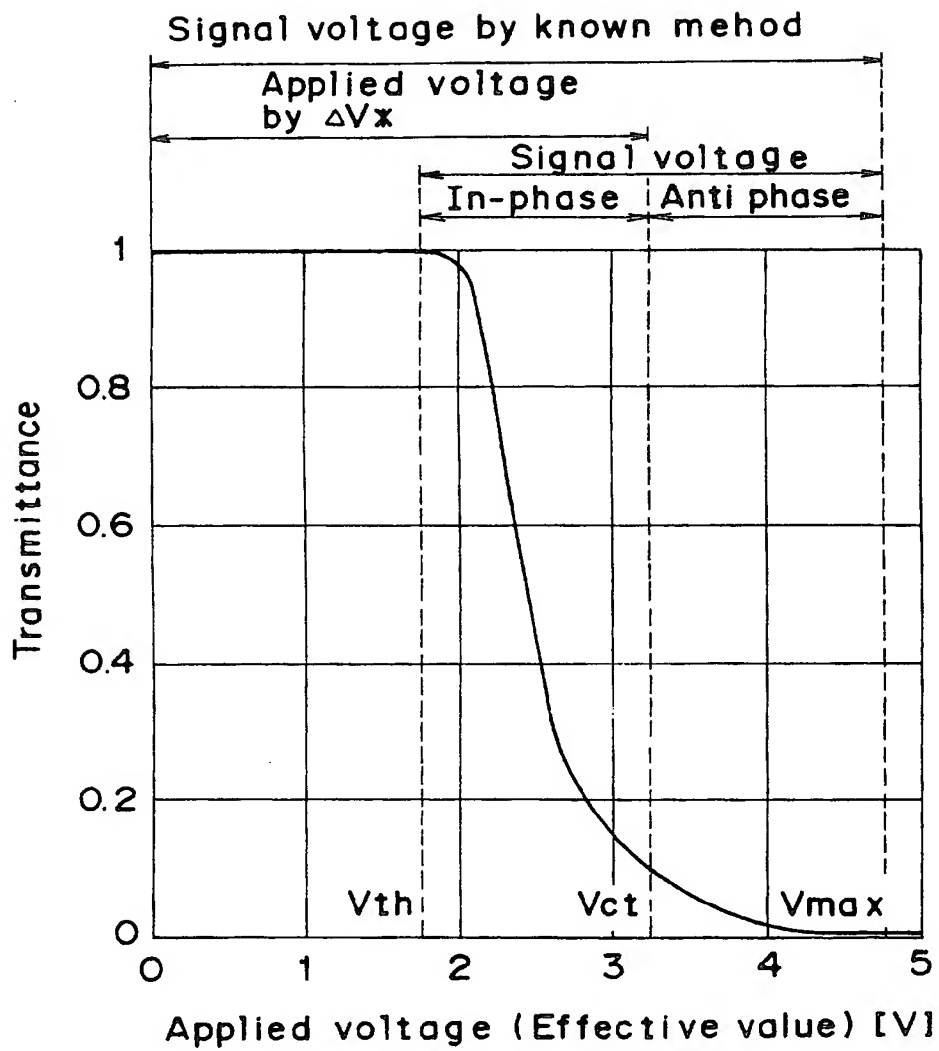
*Fig. 5*



*Fig. 6*

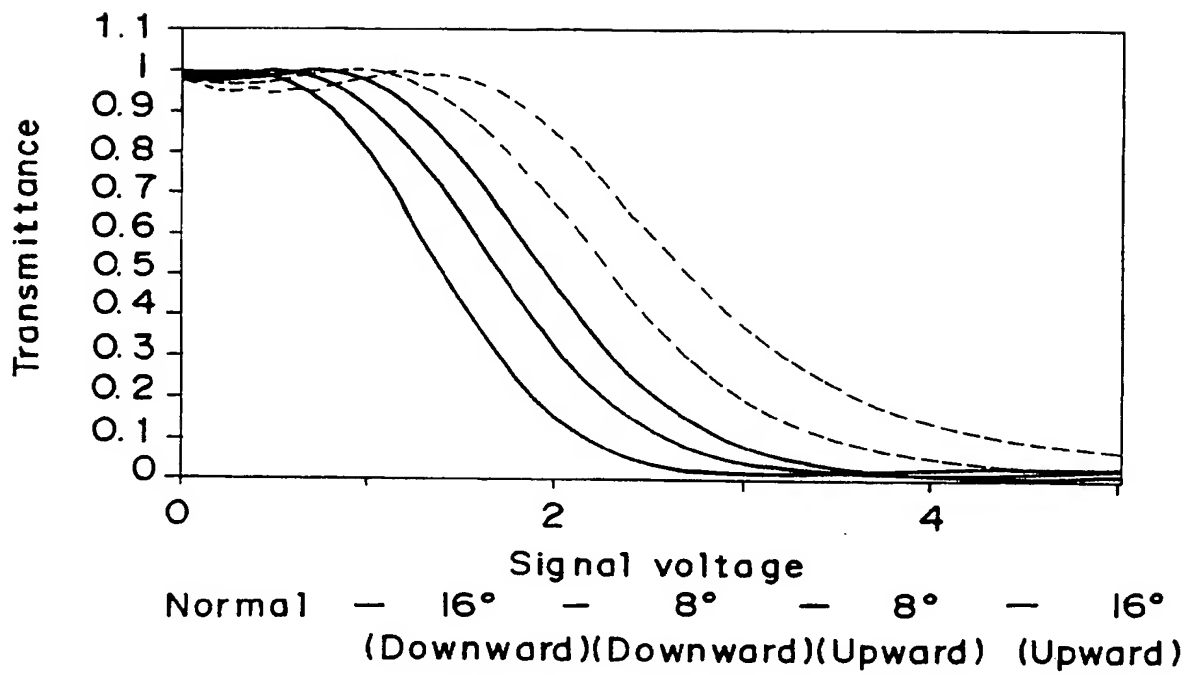




*Fig. 8*



*Fig. 9*



*Fig. 10*

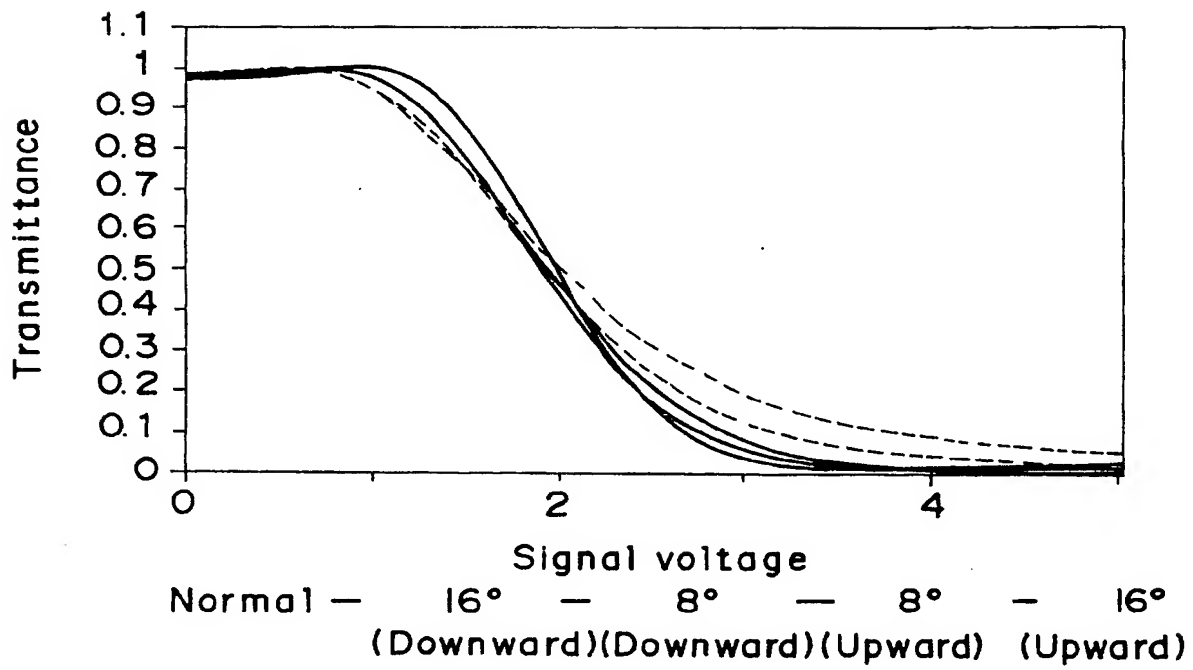
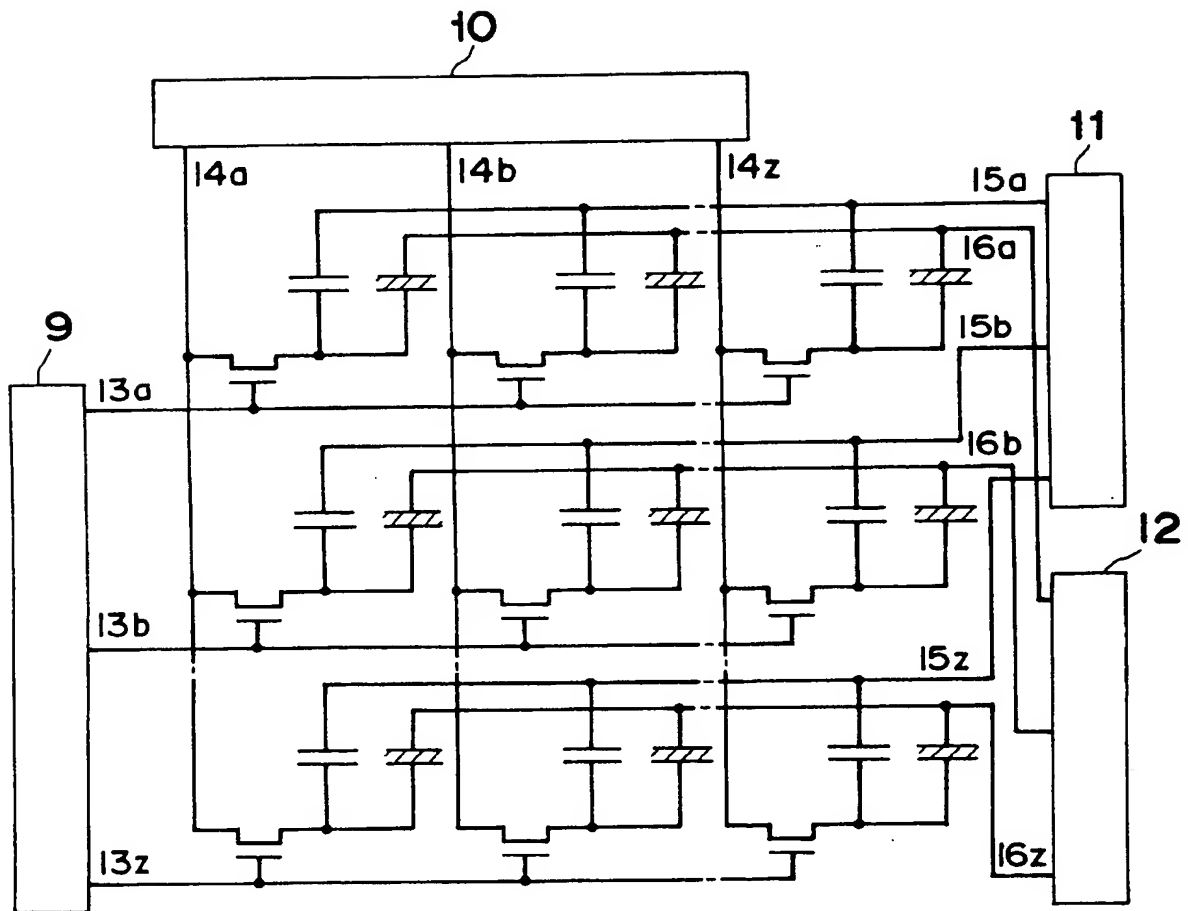
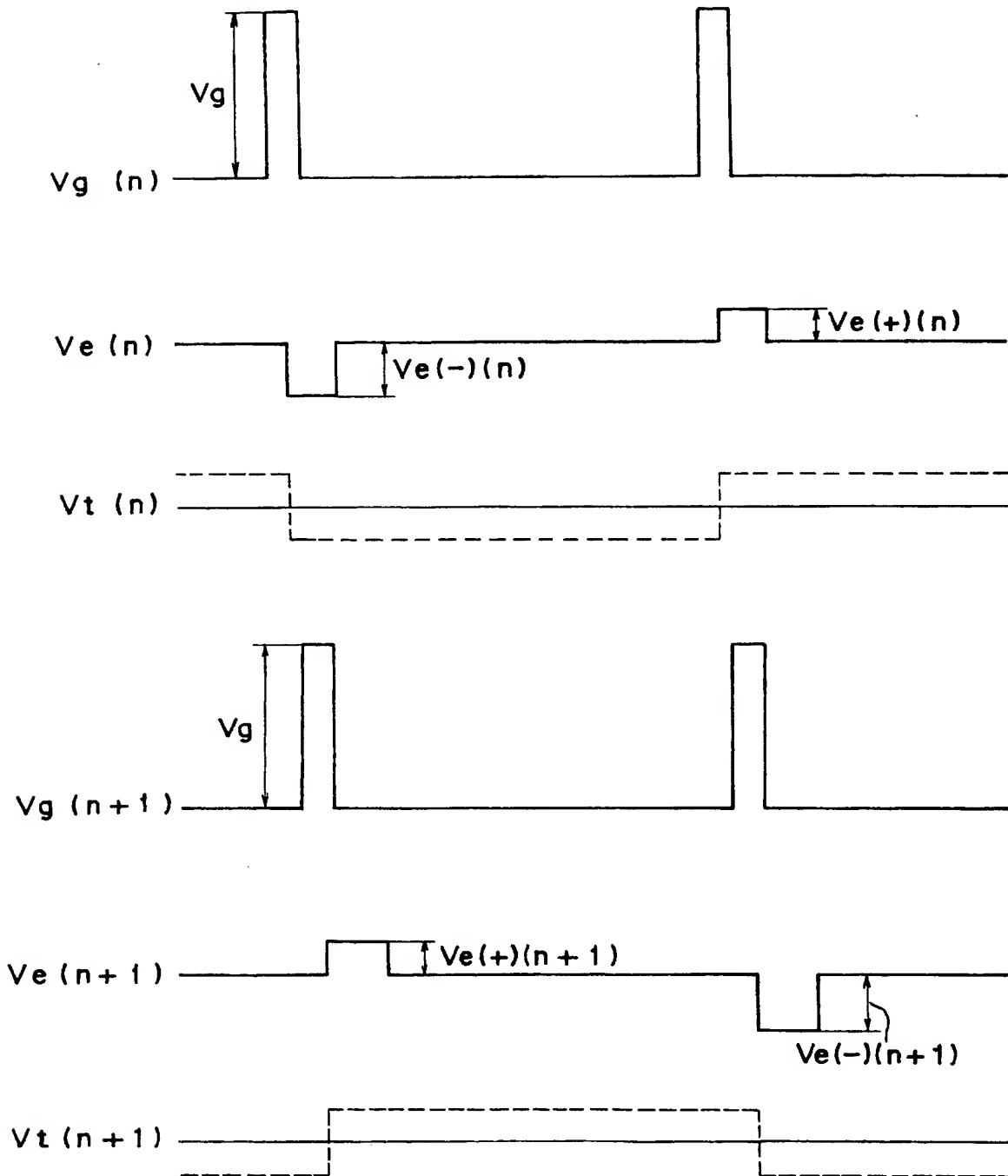


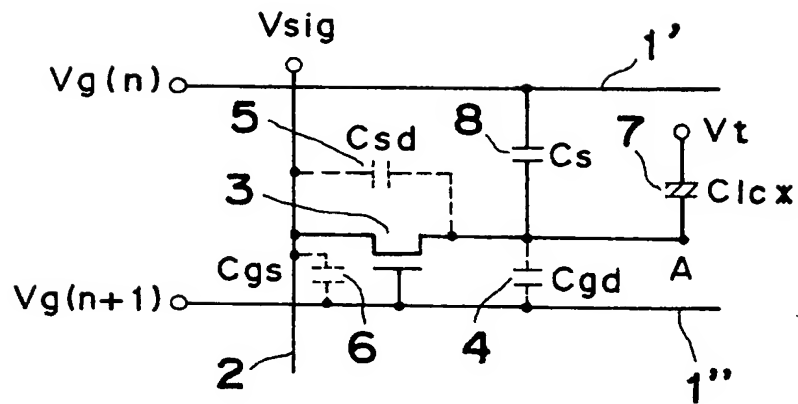
Fig. 11



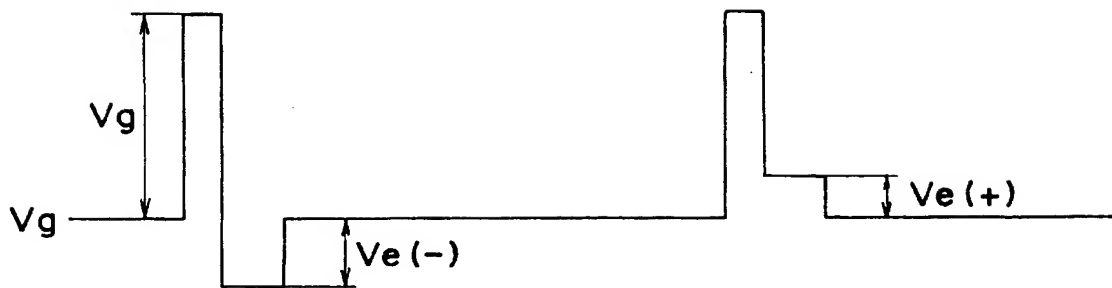
*Fig. 12*



*Fig. 13*



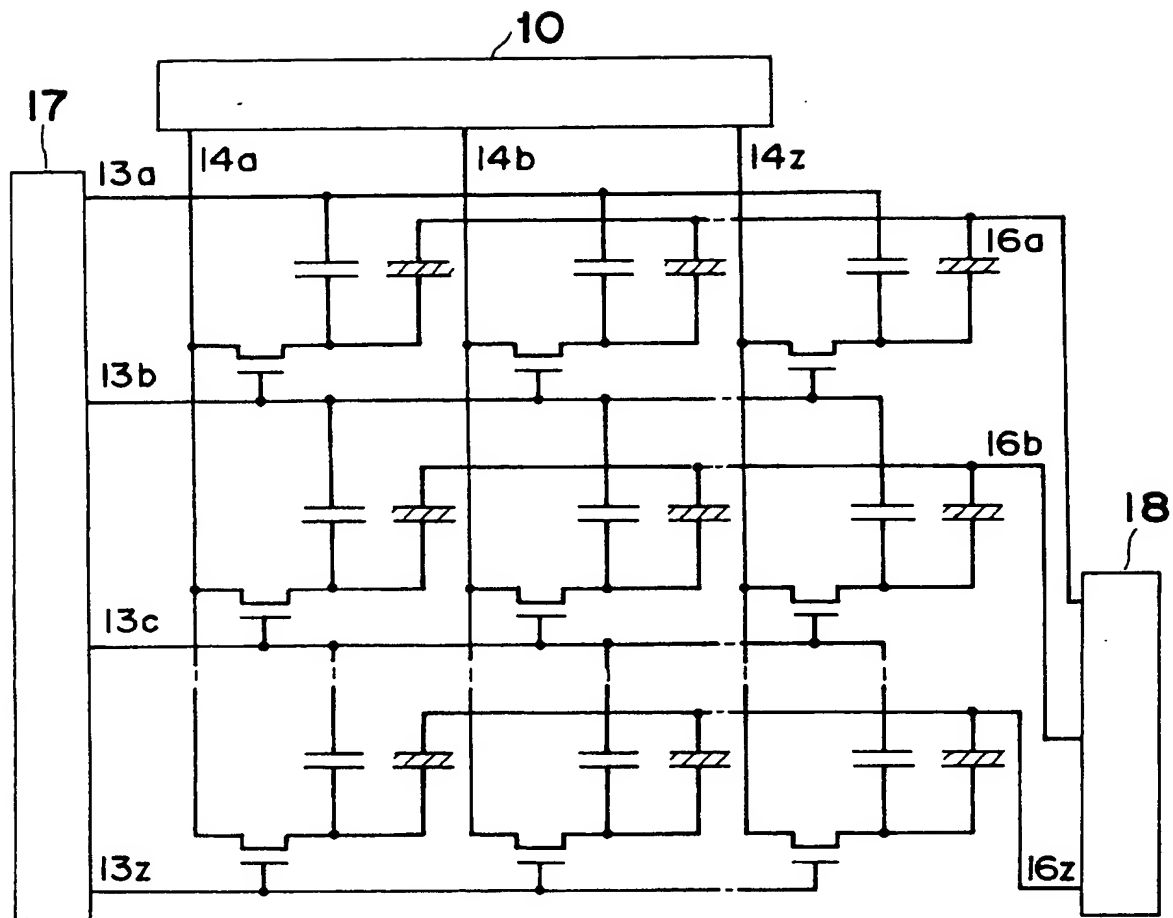
*Fig. 14 a*



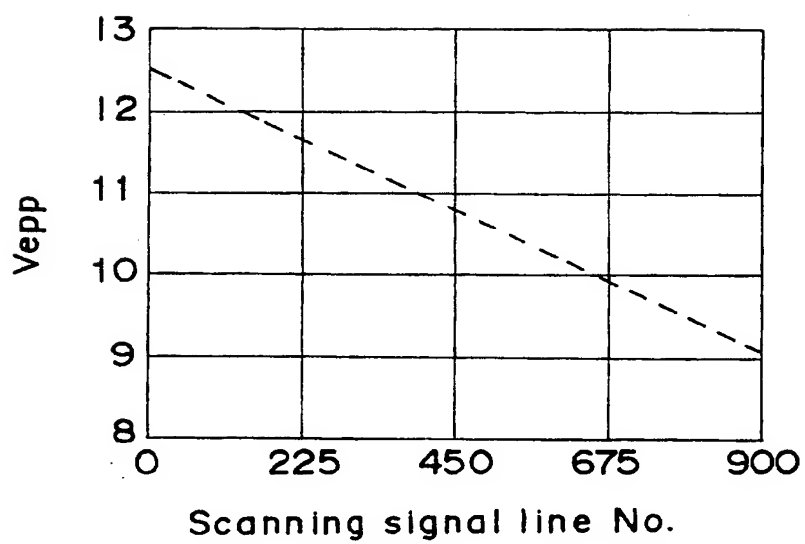
*Fig. 14 b*



Fig. 15

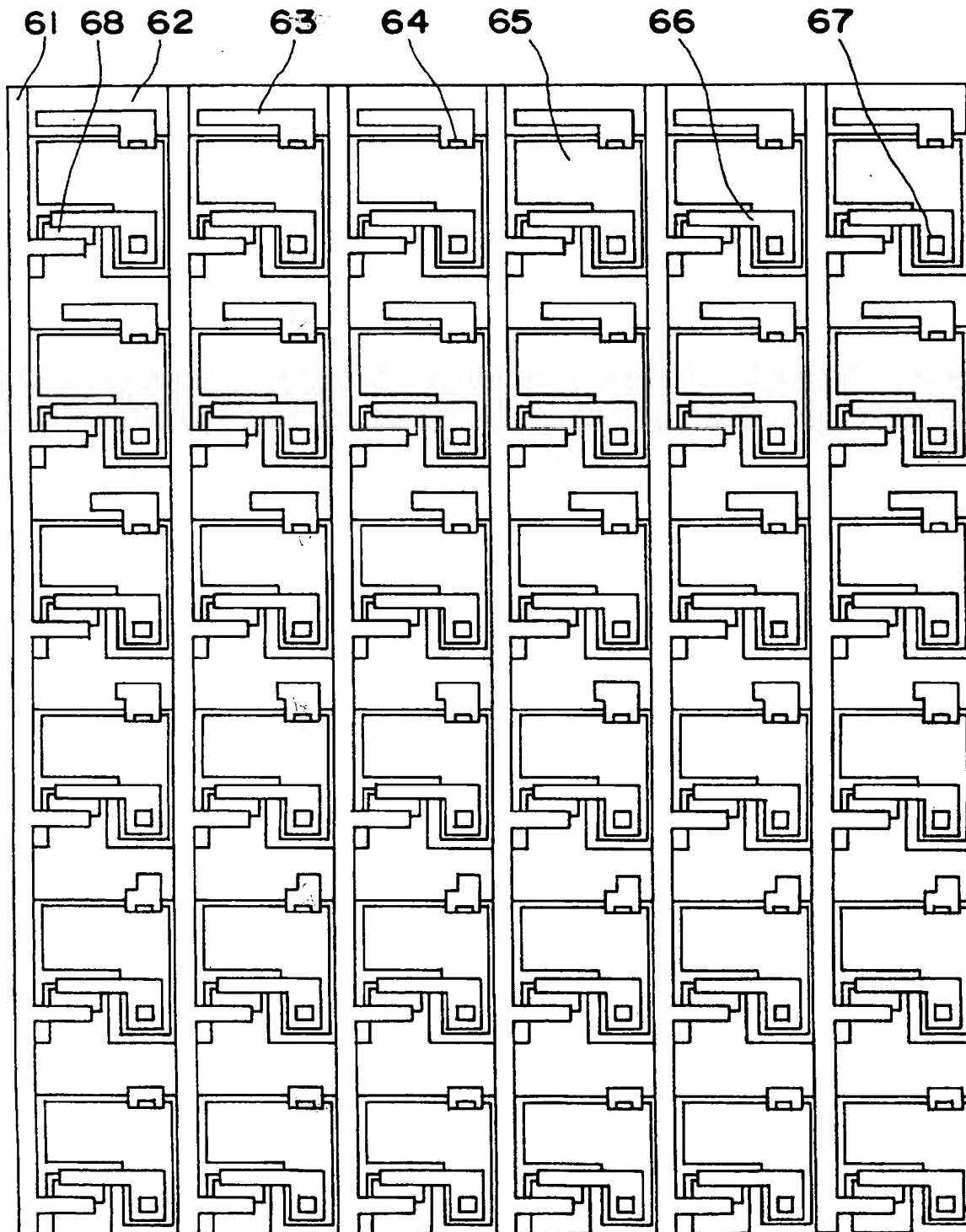


*Fig. 16*





*Fig. 17*



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**EUROPEAN PATENT APPLICATION**

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Int. Cl.<sup>5</sup>: **G02F 1/136**, **G02F 1/1337**,  
**G09G 3/36**

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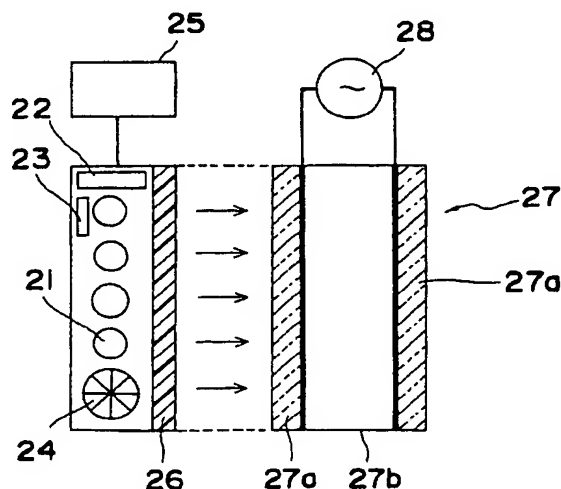
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⑤4 Active matrix liquid crystal display.

⑤7 An active-matrix liquid crystal display including a liquid crystal panel (27) in which temperature, tilt angle, driving voltage or storage capacity gradually change from an upper portion of the liquid crystal panel (27) towards a lower portion of the liquid crystal panel (27), in order to improve the uniformity of contrast and brightness.

**Fig. 3**





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## EUROPEAN SEARCH REPORT

Application Number  
EP 93 11 1573

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	PATENT ABSTRACTS OF JAPAN vol. 10, no. 206 (P-478) 18 July 1986 & JP-A-61 047 933 (SHARP) 8 March 1986 * abstract *	1	G02F1/136 G02F1/1337 G09G3/36
A	--- PATENT ABSTRACTS OF JAPAN vol. 12, no. 240 (P-727) 8 July 1988 & JP-A-63 032 524 (TOKYO ELECTRIC) 12 February 1988 * abstract *	1	
D,A	--- PATENT ABSTRACTS OF JAPAN vol. 11, no. 230 (P-599) 28 July 1987 & JP-A-62 043 624 (SEIKO EPSON) 25 February 1987	1	
Y	* abstract *	15,16	
P,X	--- PATENT ABSTRACTS OF JAPAN vol. 17, no. 138 (P-1505) 22 March 1993 & JP-A-04 313 723 (MITSUBISHI) 5 November 1992 * abstract *	1	
A	--- EP-A-0 337 493 (CASIO) * page 3, line 31 - line 47 *	1	TECHNICAL FIELDS SEARCHED (Int.Cl.5) G02F G09G
X	--- PATENT ABSTRACTS OF JAPAN vol. 11, no. 97 (P-560) 26 March 1987 & JP-A-61 249 021 (CITIZEN) 6 November 1986 * abstract *	2	
X Y A	--- EP-A-0 373 565 (MATSUSHITA)  * column 5, line 17 - column 6, line 12; claims; examples 1-4 *	3-14 15,16 17-20	
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 21 July 1994	Examiner Wongel, H
<b>CATEGORY OF CITED DOCUMENTS</b> X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application I : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1501 (03/83) (PAC01)



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### CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

- ☐ All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.
- ☐ Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claims:
- ☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

### LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions.

namely:

- see sheet B -

- ☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- ☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:
- ☐ None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:



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## EUROPEAN SEARCH REPORT

Application Number  
EP 93 11 1573

### DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	PATENT ABSTRACTS OF JAPAN vol. 16, no. 355 (P-1394) 30 July 1992 & JP-A-04 107 525 (SANYO) 9 April 1992 * abstract *	19,20	
P,X	--- PATENT ABSTRACTS OF JAPAN vol. 17, no. 543 (P-1622) 29 September 1993 & JP-A-05 150 735 (MATSUSHITA) 18 June 1993 * abstract *	1,2,19,20	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 21 July 1994	Examiner Wongel, H
<b>CATEGORY OF CITED DOCUMENTS</b> X : particularly relevant if taken alone V : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application I : document cited for other reasons & : member of the same patent family, corresponding document			

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#### LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claim 1 : A liquid crystal display in which temperature changes gradually from the upper to the lower part of the panel
2. Claim 2 : A liquid crystal in which the tilt angle changes gradually from an upper to the lower part of the panel
3. Claims 3-18 : A liquid crystal display in which the modulation signals supplied to the lines are different from one another
4. Claims 19,20 : A liquid crystal display in which the magnitude of the storage capacity changes gradually from the upper to the lower portion of the panel

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